Study on Sound Absorption Characteristics in Seepage State of Anechoic Coating

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Abstract. Aiming at the sound absorption problem of anechoic coating in water seepage state, firstly, the sound absorption coefficient of anechoic coating in infinite water area with steel plate as backing is calculated based on transfer function method and finite element method, anAd the solution results are compared with the analytical result of uniform layered medium to verify the correctness of the solution method. Secondly, the calculation model of cavity containing anechoic coating with different seepage proportion is established to analyze the influence of water seepage on the sound absorption performance of anechoic coating. The calculation results show that within the calculated frequency band, water seepage proportion has different influence characteristics on different frequency bands of anechoic coating, and with the aggravation of water seepage, the peak point of sound absorption moves to medium and low frequency, and the singular value point of sound absorption coefficient moves to high frequency; and the singularity of the valley value of the sound absorption coefficient is mainly due to the change of the cavity resonance mode. The results of this paper can provide some reference for the acoustic performance evaluation of abnormal state of anechoic coating.

Keywords: Anechoic Coating, Water Seepage, Absorption Coefficient.

1. Introduction

Underwater acoustic stealth technology is a series of measures taken to reduce the radiated noise of equipment and target intensity. By the use of acoustic stealth technology can reduce the action distance of enemy detection equipment and the probability of being found in underwater confrontation[1]. Underwater anechoic coating is a kind of polymer material laid on the surface of underwater vehicle, which can be used to sup-press hull vibration, reduce outward radiation noise and absorb the sound waves detected by enemy active sonar, which can effectively improve the concealment of underwater vehicle[2]. The typical underwater anechoic coating is composed of rubber matrix and internal cavity. By using the effects of waveform conversion and resonance, the sound absorption can be better realized in a certain frequency band, the echo intensity can be reduced, and the reflection coefficient is at a low level. At present, analytical method and finite element method are mainly used for analysis. Analytical method[3][4] is mostly used for structures with simple shape, and finite element method[5][6] is mostly used for cases with complex geometry or coupled physical field.

Compared with the uniform layer structure, the coating with cavity not only has better sound absorption effect, but also has certain sound insulation performance. The typical internal cavity mainly includes simple and regular shapes such as cylindrical, spherical, conical and horn shape. Many scholars also carry out a series of studies on the performance and indexes of the coating with cavity. To solve the problem of poor low-frequency sound insulation and pressure resistance of single cavity coating, Ke L J calculates the acoustic performance of combined cavity structure and the deformation under hydrostatic pressure, and arranges cylindrical small holes around the combined cavity to improve the low-frequency acoustic performance[7]. Dong W K considers the effect of the deformation under static pressure, based on the axisymmetric finite element simulation extracting the

shape variables, and the deformed geometric model is used to carry out the comparative analysis of sound structure coupling[8]. Dong Tian-Ren takes the layered approximation method to divide the variable cross-section conical cavity in-to multiple thin layers, and uses the transfer matrix to calculate the effects of material parameters, incident angle and cavity shape on the sound absorption coefficient[9]. Zhao Xian-Wen has studied the acoustic performance of the anechoic coating in debonding states, and analyzed the influence of parameter and media type on the acoustic performance, which can provide reference for the evaluation and health monitoring under abnormal conditions[10][11].

Water percolated into the cavity may occur in the anechoic coating during processing or after extrusion deformation. In this case, will the seepage affect its sound absorption performance? How will the sound absorption performance change? To solve these problems, this paper takes the typical cavity anechoic coating as the research object, establishes the calculation model with steel plate as the backing in infinite water area, and analyzes the effects of water seepage and the inclination angle of free surface on the sound absorption characteristics.

2. Physical Model and Method

When the sound wave is vertically incident on the surface of the scatter, due to the difference of dielectric impedance, there are some reflected waves, some transmitted waves, and the other waves will be absorbed by sound-absorbing materials. Any sound pressure point in the sound field is actually the superposition of incident sound wave and reflected sound wave. Therefore, the incident wave and reflected wave can be separated by the method of transfer function, and the reflection coefficient, transmission coefficient and sound absorption coefficient can be obtained through matrix operation. In the wireless large water area, the plane wave is vertically incident on the composite structure, as shown in Fig. 1.

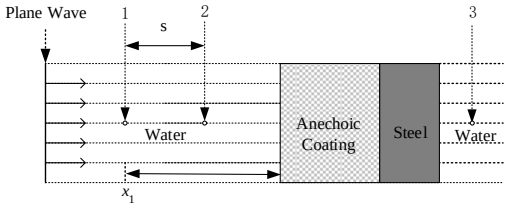


Figure 1. Schematic diagram of plane wave incidence

If the coordinate of measuring point 1 is x_1, the sound pressure value is P_1, the distance between measuring point 2 and measuring point 1 is s, and the sound pressure of measuring point 2 is P_2, at measuring point 1, the total sound field value is the superposition of incident wave and reflected wave, then the sound field of this point can be expressed as:

$$P_1 = P_I e^{jk_0 x_1} + P_R e^{-jk_0 x_1} \tag{1}$$

Similarly, the sound field value at the measuring point 2 can be expressed as

$$P_2 = P_I e^{jk_0 (x_1 - s)} + P_R e^{-jk_0 (x_1 - s)} \tag{2}$$

If Equation (1) and Equation (2) are combined and written in matrix form, then

$$\begin{pmatrix} P_1 \\ P_2 \end{pmatrix} = \begin{pmatrix} e^{jk_0 x_1} & e^{-jk_0 x_1} \\ e^{jk_0 (x_1 - s)} & e^{-jk_0 (x_1 - s)} \end{pmatrix} \begin{pmatrix} P_I \\ P_R \end{pmatrix} \tag{3}$$

If remember $B = \begin{pmatrix} P_1 \\ P_2 \end{pmatrix}$, $H = \begin{pmatrix} e^{jk_0 x_1} & e^{-jk_0 x_1} \\ e^{jk_0 (x_1 - s)} & e^{-jk_0 (x_1 - s)} \end{pmatrix}$, $P = \begin{pmatrix} P_I \\ P_R \end{pmatrix}$, we can get

$$B = HP \tag{4}$$

If matrix H is reversible, then

$$P = H^{-1}B \tag{5}$$

The reflection coefficient can be expressed as

$$R = P_R / P_I \tag{6}$$

If the sound pressure at the transmission end is P_t, for the steel backing, the transmission coefficient at the transmission end can be expressed as

$$T = P_t / P_I \tag{7}$$

After obtaining the reflection coefficient and transmission coefficient, the sound absorption coefficient can be expressed as

$$\alpha = 1 - |R|^2 - |T|^2 \tag{8}$$

3. Numerical Calculation

3.1. Validity Verification

In order to verify the correctness of the calculation solution, taking the homogeneous layered medium as an example, the fluid coating steel plate fluid model is established, the sound pressure value of the field point of the model in the sound field is calculated by the finite element method, and then the calculation matrix is compiled by the transfer function method to obtain the sound reflection coefficient, and the calculation results are compared with the analytical results. In the process of analysis, PML layer is used to simulate the infinite water area, so that the sound wave can propagate to the infinite distance without echo. The contact surface between water area and coating and the contact surface between water area and steel plate are set as fluid solid coupling surface.

The side length of a single cycle unit is 0.03m, and the height is 0.18m, and the thickness of PML layer is 0.024m.Material parameters: water density ρ_w=1000 kg/m^3, sound velocity c_w=1500 m/s, air density ρ_{air}=1.205 kg/m^3, sound velocity c_{air}=343 m/s, Young's modulus of steel plate E_s=2.16×10^{11} N/m^2, Poisson's ratio σ_s=0.28, material density ρ_s=7840 kg/m^3. Young's modulus of coating E_a=1.4×10^8 N/m^2, Poisson's ratio σ_a=0.49, material density ρ_a=1100 kg/m^3 and loss factor 0.23. The results are shown in Fig. 2.

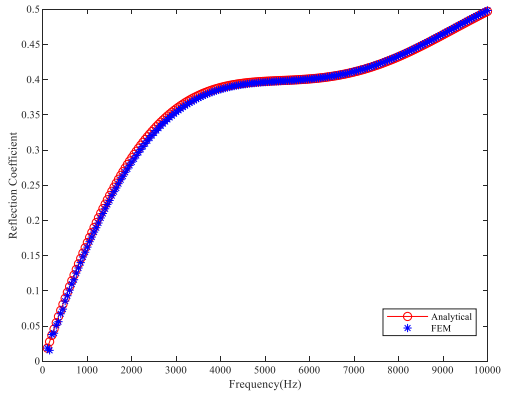


Figure 2. Comparison of FEM and Analytical results

Fig. 2 shows the result that a coating element is selected for finite element calculation and compared with the analytical. It can be seen that there are a well agree from the theoretical solution and the finite element solution, which shows that it is feasible to solve the coating structure by using the finite element method. For the more complex model, it can be calculated by the finite element method.

3.2. Influence of Water Seepage Proportion

Water seepage may occur in the anechoic coating during processing or long-term underwater use. In this section, the water seepage analysis model is established according to the ratio of water seepage volume to cavity volume. The cavities in the anechoic coating are generally arranged periodically. A unit can be taken for analysis by using the periodic boundary condition. The sound wave is incident on the surface of the structure in the medium and propagates outward after scattering. Two continuity conditions are satisfied at the sound vibration coupling interface: continuous sound pressure and continuous normal acceleration. This boundary condition is considered in the acoustic vibration coupling simulation. The specific method is to load the normal acceleration of the boundary load in the fluid domain and call the parameters of the structure domain in the coupling calculation of underwater structure and fluid. Load the boundary condition pressure in the structural domain, call the parameters in the fluid domain, and solve iteratively until the end of the calculation. The calculation diagram is as follows.

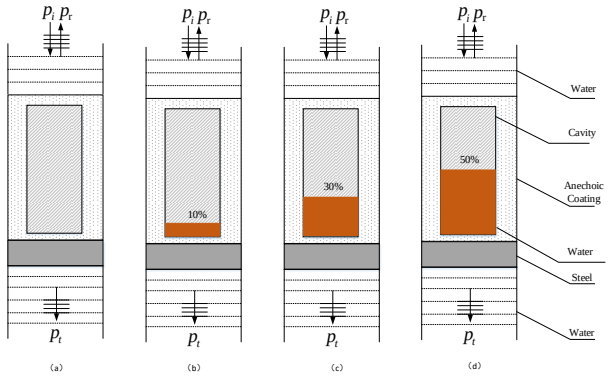


Figure 3. Calculation model of different seepage volume

Fig. 3(a) is the schematic diagram of the complete cavity coating, Fig. 3(b) shows the diagram that the water seepage volume is 10% of the cavity volume, Fig. 3(c) shows the diagram that the water seepage volume is 30% of the cavity volume, and Fig. 3(d) shows the diagram that the water seepage volume is 50% of the cavity volume. The above models are modeled by finite element method and the model is calculated to obtain the sound absorption coefficient of coating with different water seepage proportion, as shown in Fig. 4

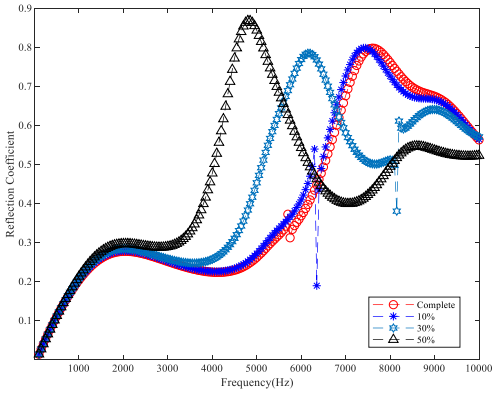
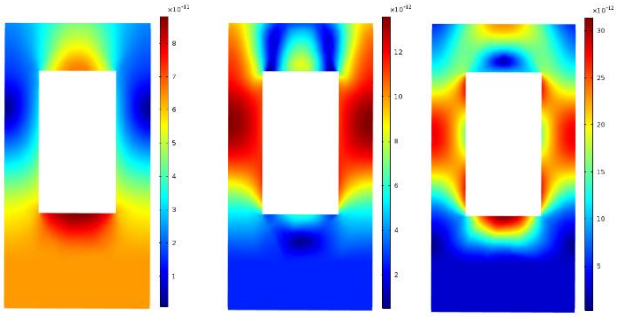


Figure 4. Calculation model of different seepage volume

Fig. 4 shows the sound absorption coefficient of the anechoic coating under different water seepage degrees in the range of 100Hz-10000Hz, and the calculation step is 50Hz. It can be seen that the influence of water seepage on the sound absorption coefficient of the structure is not very obvious in the lower frequency band and not more than 2000Hz.There is a significant influence on the sound absorption energy of the structure in the higher frequency band and it is mainly reflected in the shift of sound absorption peak. In the medium and high frequency band, with the increase of water seepage,

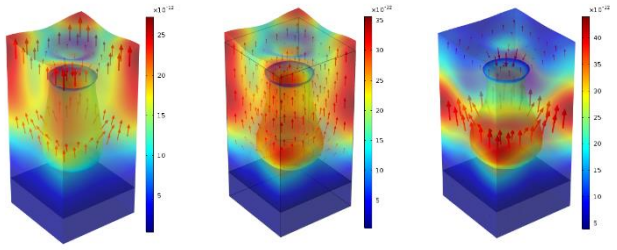
the sound absorption peak moves to the medium and low frequency, which effectively improves the sound absorption performance of medium and low frequency, but the sound absorption coefficient of high frequency is decreasing, so a certain high-frequency sound absorption performance is lost. In order to further explore the influence mechanism of sound absorption coefficient in different frequency band, the following analysis is carried out in combination with the profile displacement.



(a)1000Hz (b)4500Hz (c)7500Hz

Figure 5. Displacement nephogram at different frequency points of anechoic coating

In the middle and low frequency band, there is little difference in sound absorption coefficient regardless of water seepage and water seepage volume. In addition, with the increase of calculation frequency band, the sound absorption effect of cavity containing coating is significantly improved at high frequency. It can be seen from Fig. 5(a) that in the low-frequency band, the substrate coating close to the steel plate backing side vibrates violently, and the sound absorption of the coating is due to the stretching or compression of the coating substrate. Due to the long wavelength of low-frequency sound wave, the coating substrate close to the steel plate backing side is stretched and deformed first, then reflected at the interface between the steel plate and the coating, the sound wave enters the coating again, and the deformation of the coating consumes the energy of the incident sound wave. In the high-frequency band, the sound absorption of the coating mainly consumes acoustic energy due to the resonance between the cavity and the coating. It can be seen from Fig. 5(b) that the deformation of the coating is mainly concentrated on the cavity wall, and the displacement amplitude of the cavity wall is greater than that of the bottom. Fig. 5(c) shows that when the frequency further increases, the deformation and displacement of the cavity wall and cavity top are large, and the deformation amplitude is also significantly greater than that of the coating at the 4500Hz.

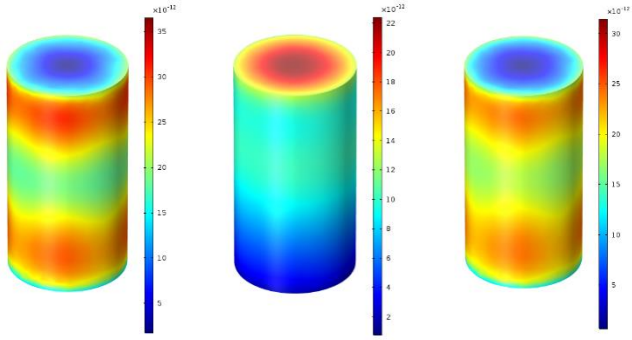


(a)10% (b)30% (c)50%

Figure 6. Displacement nephogram at 5000Hz under different water seepage proportion

It can be seen from Fig. 4 that the sound absorption performance of the coating under different water seepage proportion varies sharply in the range of 3000Hz-6000Hz. Figure 8 shows the displacement and deformation nephogram under different water seepage proportion at 5000Hz. At the same frequency, different water seepage will not change the vibration mode. The vibration around the cavity wall and the top of the coating is relatively intense, and the vibration displacement is larger than that of the coating bottom. With the increase of water seepage, the movement becomes more intense. From the cloud diagram, on the one hand, the resonance deformation of the cavity is more intense. On the other hand, when the water seepage is large, there is not only longitudinal vibration, but also transverse vibration.

In addition, after water seepage, the sound absorption coefficient appears singular point deviation and violent fluctuation. When the cavity is complete, the singular value appears at 5750Hz. When the water seepage is 10%, it moves to 6350Hz, and when the water seepage is 30%, it moves to 8150Hz. The singular point is the sound absorption valley, which means that the sound absorption effect at the frequency point is reduced and has sudden change. In order to explore the formation mechanism of the singularity, a calculation model with 10% water seepage is given, and the cavity vibration modes of the singularity and its adjacent frequency points are shown in Fig. 7.



(a)6300Hz (b)6350Hz (c)6400Hz

Figure 7. Displacement nephogram

According to the sound absorption coefficient curve in Fig. 4, under the condition of 10% water seepage, the sound absorption coefficient of the model at 6300Hz is 0.54, at 6350Hz is 0.19, and at 6400Hz is 0.44. Fig. 7 shows the cavity vibration modes at the three frequency points. It can be seen that the vibration modes of 6300Hz and 6400Hz cavities are mainly on the cavity wall, and the vibration of the end face is small. The cavity vibration at 6350Hz is mainly concentrated on the end face, and the vibration displacement of the end face is stronger than that of the wall. The maximum values of displacement at 6300Hz and 6400Hz are about 50% higher than that at 6350Hz. Therefore, the singularity is mainly due to the change of cavity vibration mode from wall vibration to end vibration at a specific frequency.

4. Conclusion

Aiming at the sound absorption characteristics of anechoic coating under water seepage proportion, combining the transfer function method and finite element method, analyzed the sound absorption characteristics of cavity coating with different water seepage and free surface inclination angle. The conclusions are as follows:

1. The numerical results based on the transfer function method combined with the finite element method are consistent with the analytical results, which can be used to calculate the sound absorption performance of the coating structure.

2. The influence of water seepage proportion on the sound absorption performance of the coating with cavity backed by steel plate has different effects in different frequency band. With the increase of water seepage, the sound absorption peak moves to low frequency and the singularity of sound absorption valley moves to high frequency.

3. The singularity of the valley value of the sound absorption coefficient is mainly due to the change of the cavity resonance mode. When the vibration mode changes from the wall vibration of the cylindrical cavity to the upper and lower surface vibration of the cavity, the sound absorption valley value appears.

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